Statistics Canada's Near Real-Time Crop Condition Assessment Program Utilizing NOAA AVHRR Data - Remote Sensing, GIS and the Internet

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ABSTRACT: This paper describes the Crop Condition Assessment Program (CCAP) developed and produced by Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada. The CCAP is a quantitative, operational system for monitoring crop and pasture/rangeland conditions throughout the Canadian prairies using NOAA AVHRR data. A customized GIS interface allows subscribers to view, analyze and compare changing crop and pasture/rangeland conditions on a near real-time basis by region, province or individual Census Agricultural Region and Census Consolidated Subdivision. Spring wheat yield was forecast using a linear regression model for the NDVI data and historical yields published by Statistics Canada. Accuracy of the spring wheat yield forecast using NOAA AVHRR data for the Canadian prairies, compared to the published Statistics Canada survey crop yields, ranged from +7.4 percent to -9.4 percent for the 1989 to 1997 period. Spring wheat yield forecasts using NOAA AVHRR data are viewed as an experimental indicator distributed to the CCAP subscribers. The official Statistics Canada crop estimates are produced from the field crop reporting surveys.

1. Introduction

National and international growing and marketing of wheat and other grains is a multi-billion dollar industry. Canada is the sixth largest producer of wheat in the world, after China, the European Union, the United States, India and Russia [Sawatzky 1998]. On average, Canada produces about 5 percent of the world's wheat, enough to feed our population of 28.8 million people four times over [Statistics Canada 1998a]. Consequently, Canada accounts for 19 percent of all wheat exports globally, making Canada the second largest wheat exporter in the world. Increasing competition among grain exporters and the instability of grain markets have underscored the importance of having accurate and timely information on the supply and demand for grain by importing and exporting nations of the world.

Remote sensing can supply the user community with an update on crop conditions over a large geographic area using a series of coarse resolution satellites. Twice daily, the entire earth's surface is imaged by the National Oceanic and Atmospheric Administration (NOAA) series of satellites carrying the Advanced Very High Resolution Radiometer (AVHRR), a five channel scanning sensor which images in the visible, near infrared and thermal infrared wavelength bands.

Vegetation monitoring using the red and near infrared AVHRR channels has been one of the most widely used indices. The Normalized Difference Vegetation Index (NDVI) correlates closely with green biomass and the leaf area index. In the 1980s, Canada began assessing the information content of the AVHRR digital data for operational monitoring of crops throughout the prairie region of western Canada [Brown et al. 1982, Glick et al. 1984, Prout et al. 1986]. Despite the spatial resolution of 1.1 km at nadir, there are many scientific publications documenting the usefulness of AVHRR data as a means of monitoring vegetation conditions on a near real-time basis [Philipson and Teng 1988,

Korporal et al. 1989, Tappan et al. 1990, Reichert et al. 1991, Bullock 1992, Quarmby et al. 1993, Reichert 1995].

Despite significant annual variations in growing conditions, it is possible to produce yield forecasts using NOAA AVHRR data. Recent findings by Doraiswamy and Cook [1995], Leprieur et al. [1996], Rasmussen [1997], and Hochheim and Barber [1998] continue to advance yield forecasting capabilities using NOAA AVHRR data. Demands placed on scientists by private industry, marketing agencies and government to produce accurate, timely production forecasts well in advance of statistical survey estimates emphasizes the importance of using remotely sensed data, Geographic Information Systems (GIS) and the Internet.

2. Canada's Crop Information System

In 1987, the Crop Information System (CIS) was initiated as a joint project between Statistics Canada, Agriculture and Agri-Food Canada, the Canada Centre for Remote Sensing, the Canadian Wheat Board, and the Manitoba Remote Sensing Centre. The CIS was initiated because traditional procedures for reporting crop conditions and forecasting production in Canada relied primarily upon meteorological data and farm survey information.

3. Statistics Canada's Crop Condition Assessment Program

In 1988, the Crop Condition Assessment Program (CCAP) was developed and implemented by Statistics Canada. Statistics Canada's original interest in establishing a CCAP was to replace the Telegraphics Report Program (TRP) that had been discontinued for budgetary reasons. The TRP was a weekly report of crop growth submitted by 160 individuals from across the country. These reports were supplementary to Statistics Canada's farm surveys on yield and provided information on crop development throughout the growing season. The discontinuation of the TRP left a large data gap in the crop reporting program, and the CCAP was evaluated as an ideal project to augment the crop reports. The benefits of monitoring vegetation conditions across the prairies, in absence of the TRP, were immediately evident during the drought year of 1988. The success further reinforced the role of remote sensing as an integral part of a CCAP, therefore, in 1989 the CCAP was made available to subscribers outside of Statistics Canada.

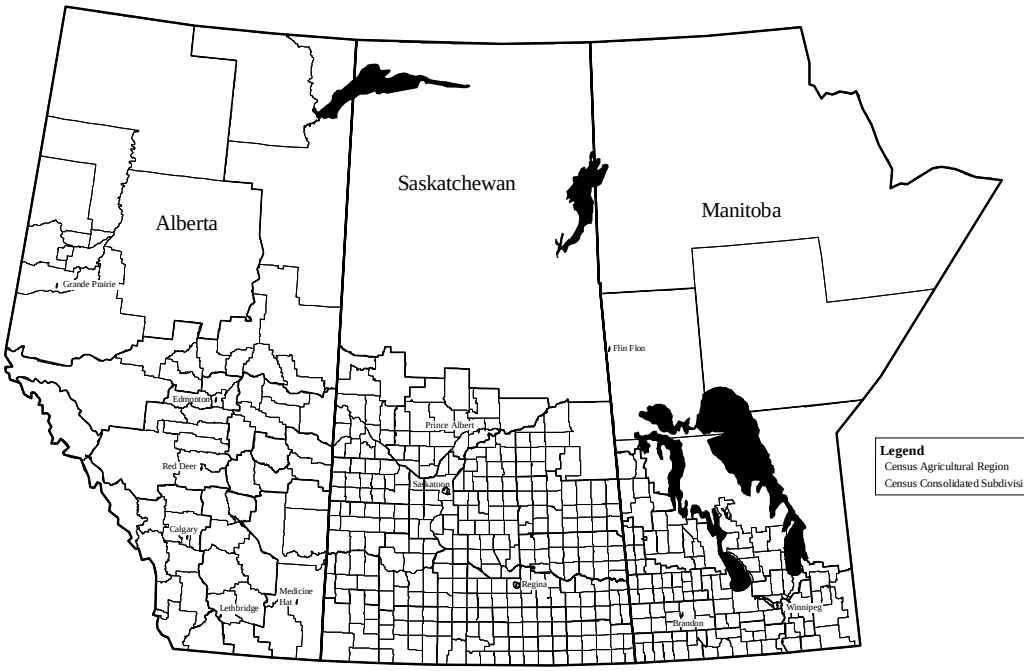
4. Data Processing

As part of the Canadian CIS program, NOAA AVHRR data for the prairie region of western Canada are collected daily throughout the crop growing season (April-October) at the satellite receiving station, Prince Albert, Saskatchewan. These data are transferred to the Manitoba Remote Sensing Centre (MRSC) where processing is performed using the Geocomp system [Robertson et al. 1992]. The Geocomp system performs sensor calibration and optionally atmospheric correction, followed by precise geometric registration [Cihlar and Huang 1994]. As part of the CIS program within Geocomp, daily images of the prairie region of western Canada are used to produce a weekly, seven-day, cloud free composite image for channels 1, 2, 4 and NDVI. Statistics Canada retrieves the composites for channels 1, 2 and 4 from the MRSC via a 56K modem connection over regular phone lines. It is substantially faster, however, to calculate the NDVI in-house at Statistics Canada rather than download the file via a modem.

Although the seven-day composite substantially reduces cloud cover problems inherent with daily images, the process does not always produce a composite image that is completely free of cloud

influence. Conclusions by Hochheim and Barber [1998] support the earlier findings of Statistics Canada that cloud influence contained in a composite must be addressed to increase the accuracy and usefulness of the CCAP products. Cloud-affected pixels not eliminated in the compositing process are easily recognized in the channel 1 composite. Channel 1 is one of the input channels required in producing the NDVI composite, consequently, any cloud influence remaining in the channel 1 composite is carried forward into the NDVI composite calculation. Therefore, to minimize statistical errors introduced by clouds, Statistics Canada generated a constant threshold cloud mask based on the channel 1 AVHRR composite. The cloud mask is applied to the NDVI composite ensuring that only cloud free pixels are used when computing the NDVI statistics for the Census Agricultural Regions (CAR) and Census Consolidated Subdivisions (CCS) across the prairies (Figure 1).

Figure 1. Census Agricultural Regions and Census Consolidated Subdivisions, Prairie Provinces, 1996



5. Geographic Information System Interface

During the early years of the CCAP, Statistics Canada provided subscribers with weekly reports on crop conditions four days after the composites were available from the MRSC. These reports were available only in paper format and were delivered by hand to subscribers using commercial courier services. Nearly 10 years later, the weekly CCAP updates are available to subscribers within two hours of Statistics Canada receiving the composites from the MRSC. All data processing is digital end-to-end and the CCAP deliverables are made available to the subscribers at the same time every week via the electronic File Transfer Protocol (FTP). Subscribers are immediately alerted every week via e-mail as soon as the FTP site has been updated.

Since 1996, Statistics Canada has provided CCAP subscribers with a customized GIS interface. This interface provides value-added processing, ease of access and program flexibility. Subscribers can view several types of image and map products, statistical data, and NDVI curves, all of which are updated weekly by Statistics Canada. Image products show vegetation conditions on a pixel-by-pixel basis for the entire prairie region of western Canada. Map products illustrate the predominant vegetation condition by CAR and CCS. Image and map products include:

1) comparison of any week of the current growing season with the previous week of the same growing season,
2) the current week with the same week of the previous growing season,
3) the current week with the same week of the normal, and
4) percent comparison of the current week with the maximum NDVI value within the normal.

The normal is an average of the NDVI channel for the crop years from 1987 to the year previous to the present growing season (i.e., the 1998 normal is the average of all the years from 1987 to 1997). Years of drought and record production are included in the calculation of the normal. Using the GIS interface, subscribers can view agricultural areas of importance for grains and oilseeds, and areas containing pasture and rangeland individually or combined. This type of qualitative analysis allows users to quickly assess how much and where week-to-week conditions have either deteriorated, remained unchanged or improved. Water bodies, rivers, roads, cities and CAR and/or CCS boundaries are overlaid onto the image to aid in area location.

A detailed, quantitative analysis within the GIS system is accomplished by calculating the mean NDVI value on a weekly basis for crop and pasture/rangeland masks, for each of the 40 CARs and for the almost 500 CCSs. As previously mentioned, pixels influenced by clouds are excluded from the calculation of the mean NDVI statistics. Each mean NDVI curve by selected CAR and/or CCS can be viewed, analyzed and compared to other years within the statistical archive. Users have the flexibility to choose the comparison years and can electronically export the data or the NDVI curves into reports or presentations.

6. Satellite Yield Model

The most extensive crop in the prairie region of western Canada is spring wheat. In the 10 years prior to 1998, there has been an average of 12.5 million hectares of spring wheat seeded on an annual basis across the prairies of western Canada, or about 50 percent of the total area seeded to the six major grains. Barley, the next largest crop, accounts for about 4.2 million hectares on an annual basis. The coarse resolution of the AVHRR sensor makes differentiating one crop from another impossible. Information acquired by the satellite over the prairies is dominated by spring wheat, therefore, changes in NDVI are predominantly a result of changing spring wheat conditions. Consequently, the linear regression yield model used for this study deals only with spring wheat.

NDVI curves typically reach their maximum peak between early July and mid-August and decline as the vegetation ripens. During this period, the historical NDVI values for each CAR were correlated with Statistics Canada's survey crop yields using a linear regression model. The linear relationship was applied to the current season NDVI value and a forecast yield at the CAR level was calculated. Spring wheat production was forecast by multiplying the forecast spring wheat yield by the seeded area from the current season, small area statistics captured by Statistics Canada's field crop reporting series. Small area statistics were made available to subscribers through the Agri-Stats module of the CCAP.

Production forecasts at the CAR level were aggregated to the provincial and prairie level and a weighted forecast yield provided.

Preliminary spring wheat yield forecasts using the linear regression model compared with Statistics Canada's final published spring wheat yield estimates vary from year to year (Table 1). For the period from 1989 to 1997, the spring wheat yield forecast accuracy ranged from +7.4 percent to -9.4 percent.

Table 1. Preliminary Spring Wheat Yield Forecasts for the Prairies Region of Western Canada based on NOAA Satellite Data

	1989	1990	1991	1992	1993	1994	1995	1996	1997
Forecast[1] (bu/ac)	28.8	34.9	31.3	31.0	29.0	29.5	29.4	35.2	33.2
STC Publication[2] (bu/ac)	26.8	33.7	33.1	31.3	32.0	30.7	32.3	36.1	31.5
Forecast vs Published	7.4%	3.6%	-5.5%	-0.9%	-9.4%	-3.9%	-9.0%	-2.6%	5.6%

[1] These forecasts are viewed as experimental indicators distributed to CCAP subscribers for evaluation purposes only. The official Statistics Canada crop estimates are based on the Field Crop Reporting Surveys.
[2] Statistics Canada, Field Crop Reporting Series, 1998b.

7. Future Direction

All products supplied to the CCAP subscribers are in a GIS digital format. Although subscribers have been quick to recognize the benefits of the CCAP program for near real-time analysis, the resistance to purchase a relatively inexpensive GIS software package remains a sensitive issue for some subscribers. To eliminate this problem, Statistics Canada is currently "Web-enabling" the CCAP program for the 1998 growing season. Subscribers will be able to access a password-protected account containing the historical and current CCAP information via a Web browser on the Internet. The benefits are obvious for client and provider — the client saves money by not having to invest in a GIS package to view the CCAP products, while the provider can expand the client base provided the client has access to the Internet. Changes, revisions and updates are transparent to the client improving efficiency, ease of access and program flexibility.

8. Conclusions and Recommendations

The CCAP is an operational system that provides information about crop and pasture/rangeland conditions and expected spring wheat yields across the Canadian prairies in a timely and reliable manner. These early assessments are invaluable to decision-makers and analysts within government agencies, grain marketing bodies, transportation companies, chemical companies, banks and insurance companies for better management of agricultural prices and distribution. It is recommended that further research be completed in the following areas to determine if improvements to the CCAP are possible by:

- addressing the issue of cloud cover and cloud influence associated with a longer compositing period;
- expanding the area covered from the prairie agricultural region to the agricultural region of western Canada;
- updating the land cover mask of western Canada derived from Landsat TM data;
- revising the statistics for the current and historical crop years based on the new land cover mask at the CAR and CCS level;

- developing necessary regression equations that would allow the NDVI technique to be extended to other major crops within western Canada or other parts of the world;
- incorporating the strengths of agro-meteorological and remotely sensed data into the yield models;
- exploring faster, more efficient transfer hardware and software packages that would enable accelerated transmission rates of data via modem or preferably the Internet; and
- develop a user-friendly interface on the Internet for ease of access and use.

These improvements would allow the CCAP to remain at the forefront of technology for providing detailed, objective and timely crop information to subscribers.

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